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ABSTRACT

The preliminary Palmer Drought Severity Index (PDSI) is calculated and disseminated operationally by the National Oceanic and Atmospheric Administration/United States Department of Agriculture's (NOAA/USDA) joint agricultural weather facility. On an operational basis, this index is more aptly described as the Palmer Hydrological Drought Index (PHDI) in order to differentiate it from its hindcast value, the PDSI. Using the PHDI the approximate precipitation required to ameliorate or terminate any ongoing drought was calculated across the United States for various prescribed periods, i.e., 1, 2, 3, and 6 months. The climatological probability of receiving at least the needed precipitation was calculated using the gamma distribution. The probability calculations indicate that in many portions of the country it is quite unlikely that serious drought can be terminated in a single season or even in two seasons. Furthermore, due to the varying climatologies across the country, the probability of ending or ameliorating a drought varies both spatially and temporally in a systematic manner across the United States. The annual precipitation cycle and the probability of receiving substantial excess precipitation above normal (the skewness of the precipitation distribution) are two important characteristics of drought termination and amelioration in the Palmer Drought Model.

1. Introduction

One of the most frequently used drought indices in the United States is the Palmer Drought Severity Index (PDSI), Palmer (1965). The index has been used in countless research studies (e.g., Karl and Young, 1986; Karl, 1986b; Stahle et al., 1985; Alley, 1985; Karl, 1983; Diaz, 1983; Karl and Koscielny, 1982; Karl and Quayle, 1981; Rosenberg et al., 1980; Rosenberg, 1978a,b; Mitchell et al., 1979; Klugman, 1978; Haines et al., 1976; Skaggs, 1975). It has also been used on an operational basis to assess the severity of droughts and wet spells across the United States. The National Weather Service (NWS) transmits its operational version of the PHDI over the national facsimile circuits twice monthly, and it is made available and updated weekly, year round, on the NWS's Automated Field Operations System (AFOS). A number of users of the index have reported the index as a useful tool to monitor ongoing droughts (U.S. Department of Commerce, 1981). Furthermore, recent analyses (Karl, 1986b; Whittemore et al., 1986; McGregor, 1985; McGregor et al., 1986; Stahle et al., 1985; Karl and Young, 1986; Alley, 1984, 1985; Karl, 1983; Karl and Quayle, 1981) have also demonstrated that, despite several assumptions used in the water balance calculations and the empirical nature of some of the standardizing coefficients, the PDSI or the PHDI can be, if used appropriately, a useful tool for both research and real-time drought assessments.

The purpose of this study is twofold. First, its purpose is to provide users of the PHDI during severe drought conditions some quantitative measure of the climatological probability that any ongoing drought can be terminated or ameliorated over some prescribed period. Second, several characteristics of drought climatology across the United States are identified, aiding our understanding of the behavior of droughts in this country.

Despite the fact that other articles (Karl, 1983; Karl, 1986a; Alley, 1984, 1985) have pointed out the difference between the PHDI, PDSI, and the operational version of the PDSI, a few additional words are pertinent. The differences between the PHDI and the PDSI occur near the end of a drought (or wet spell). The PDSI abruptly returns to near-normal levels (-0.5 or larger) during the *first* month in a sequence of months with sufficient moisture to end a drought, but the PHDI is usually more gradual in its return to near-normal levels. The PHDI changes to a new spell only when the moisture needs associated with recharge, demand, and runoff have been brought back to normal or above normal, i.e., the *last* month in a sequence of months with sufficient moisture to end a drought. The operational PDSI as calculated by the NWS must necessarily operate similarly to the PHDI. This is because without prior knowledge of subsequent weather it is impossible to know whether a wet single month, or a few wetter-than-normal months, will be the beginning of a new spell of wet or near-normal weather with sufficient moisture to terminate an ongoing drought, or whether they are just a temporary respite in a longer sequence of dry months ahead.

2. The precipitation required to end a drought

The assumptions, strengths, weaknesses, and limitations of the Palmer Drought Model (PDM) have been the topics of a series of recent studies by Alley (1984, 1985) and Karl (1983; 1986a,b). These papers describe various aspects of the PDM as originally conceived by Palmer (1965). These publications contain numerous details regarding the PDM calculation procedures and will not be repeated. Instead, one specific area of the PDM calculations will be elaborated upon, namely, the calculations which directly pertain to the precipitation required to end or ameliorate a drought. In a spell of dry weather the PDSI is defined by

$$\mathrm{PDSI}_i = 0.897\,\mathrm{PDSI}_{i-1} + (Z_i/3) \tag{1}$$

where i is the month of interest and Z is the "moisture anomaly index" or simply the Z-index. The Z-index is given by

$$Z_i = (P_i - \hat{P}_i)K_i \tag{2}$$

where P is the observed precipitation, $\hat{P}$ the climatologically appropriate precipitation for existing conditions (CAFEC), and K a standardization constant. The value of $\hat{P}$ can be obtained by

$$\hat{P}_i = \alpha_i \mathrm{PE}_i + \beta_i \mathrm{PR}_i + \gamma_i \mathrm{PRO}_i - \delta_i \mathrm{PL}_i, \tag{3}$$

where PE is the potential evapotranspiration, PR the potential recharge of soil moisture, PRO the potential runoff and PL the potential moisture loss from the soil. The parameters α, β, γ, and δ are defined over some calibration period by the following:

$$\alpha = (\overline{\mathrm{ET}})/(\overline{\mathrm{PE}}) \tag{4}$$

$$\beta = (\bar{R})/(\overline{\mathrm{PR}}) \tag{5}$$

$$\gamma = (\overline{\mathrm{RO}})/(\overline{\mathrm{PRO}}) \tag{6}$$

$$\delta = (\bar{L})/(\overline{\mathrm{PL}}) \tag{7}$$

where ET is the evapotranspiration, R the recharge, RO the runoff, and L the soil moisture loss. The overbar denotes mean conditions. Recent articles by Karl (1983), Alley (1984), and Karl (1986) discuss the calculation of the index itself and its sensitivity to several issues of interest, i.e., calibration period, evapotranspiration estimates, runoffs, etc.

TABLE 1. Classes for wet and dry periods (from Karl, 1986a).

Approximate cumulative frequency (%)	Category	PDSI or PHDI
≥96	Extreme wetness	≥4.00
90–95	Severe wetness	3.00 to 3.99
73–89	Mild to moderate wetness	1.50 to 2.99
28–72	Near normal	−1.49 to 1.49
11–27	Mild to moderate drought	−1.50 to −2.99
5–10	Severe drought	−3.00 to −3.99
≤4	Extreme drought	≤−4.00

TABLE 2. The smallest Z-index (Z_e) required to end droughts of various intensities over various time periods.

PHDI	No. of months: 1	2	3	6
−2	3.88	1.75	1.06	0.34
−3	6.57	3.03	1.86	0.69
−4	9.26	4.30	2.66	1.02
−5	11.96	5.57	3.47	1.36
−6	14.64	6.85	4.27	1.69

By definition, when the PDSI = −0.5, any existing drought is assumed to have ended. Table 1 (Karl, 1986a) contains some qualitative and quantitative descriptions of various magnitudes of the PDSI, Z-index and PHDI based on data across the United States during the years 1931–84. As a special case, when PDSI_i in (1) is set equal to −0.5, Z will be referred to as the Z-index needed to end the drought, Z_e. In order to calculate the precipitation required to change the PDSI from any given level of drought in month $i-1$ to −0.5 in month i, the first step required is to rewrite (1) as

$$Z_e = -1.50 - 2.6910\,\mathrm{PDSI}_{i-1}. \tag{8}$$

Likewise, the Z-index required to ameliorate an existing drought, with PDSI less than −2, to PDSI_i equal to −2 will be referred to as Z_a, the Z-index required to ameliorate an existing drought. By setting PDSI_i in (1) to −2, the one-month value of Z_a required to ameliorate the drought in month i is given by

$$Z_a = -6.00 - 2.6910\,\mathrm{PDSI}_{i-1}. \tag{9}$$

It is possible to solve (8) and (9) for various values of PDSI_{i-1}. These results are given in column 1 of Tables 2 and 3. In addition, the minimum value of Z required to end or ameliorate a drought can be calculated over periods longer than a month by solving a set of simultaneous equations for Z_e or Z_a, whereby the PDSI at time $i-2$, $i-3$, etc., is expressed in terms of the PDSI for the previous month. For example,

$$\mathrm{PDSI}_i = 0.897\,\mathrm{PDSI}_{i-1} + Z_e/3 \tag{10}$$

TABLE 3. The smallest Z-index (Z_a) required to ameliorate a drought to a −2 intensity over various time periods.

PHDI	No. of months: 1	2	3	6
−2	−0.62	−0.62	−0.62	−0.62
−3	2.07	0.65	0.18	−0.28
−4	4.76	1.93	0.98	0.05
−5	7.46	3.20	1.79	0.39
−6	10.15	4.47	2.59	0.72

$$\mathrm{PDSI}_{i-1} = 0.897\,\mathrm{PDSI}_{i-2} + Z_e/3 \quad (11)$$

where $\mathrm{PDSI}_i = -0.5$. In (10) and (11), Z_a could be substituted for Z_e if $\mathrm{PDSI}_i = -2$. The results of solving for Z_e and Z_a for various sets of simultaneous equations lead to the values given in Tables 2 and 3 for 2, 3 and 6-month ending and amelioration times of droughts of various intensities.

Equation (2) can be rewritten as

$$P_i = (Z_i/K_i) + \hat{P}_i \quad (12)$$

in order to calculate the precipitation needed to end or ameliorate a drought. Since Z_i is given by Tables 2 and 3 and K_i is known for each month (cf. Karl, 1983; Alley, 1984; Palmer, 1965), the only remaining variable to be assigned a value in order to calculate P_i is $\hat{P}_i$. From (3) it is apparent that $\hat{P}_i$ cannot be calculated until the end of a month, so it would appear that the determination of P_i is not possible until after the value of PE_i and PL_i are calculated. The PL_i is a function of PE_i, and of course PE_i cannot be calculated until the month has ended (Palmer, 1965). Additionally, there are many potential combinations of PL_i, PE_i, PRO_i, and PR_i that are possible. An effective solution to this apparent dilemma is to regress the values of $\hat{P}_i$ that have been historically observed against the PDSI_{i-1} for each month during droughts. Such linear regressions were calculated each month for 344 climate divisions in the United States, using data spanning the years 1931–84. The results from two drastically different climates are depicted in Fig. 1. In dry climates $\hat{P}$ is considerably lower than in wet climates, as indicated in Fig. 1. Generally, when the soil moisture supply has high variability, as during summertime conditions in northern Alabama and wintertime conditions in southern California, $\hat{P}$ will increase as the PHDI decreases. When the index's soil moisture supply has little year-to-year variability, as in the winters in northern Alabama or the summer of southern California, the $\hat{P}$ does not change with respect to the intensity of the drought. This property is attributed to the fact that in (3), three of the four terms are related either directly or indirectly to soil moisture supply.

The strength and significance of the relationships developed between the PHDI at the end of the month and the $\hat{P}$ for the subsequent month are underestimated by the correlation coefficients of the data used to derive the lines of best fit between individual monthly values of $\hat{P}_i$ and PHDI_{i-1} as depicted in Fig. 1. This is because $\hat{P}$, as shown in Fig. 1, is also a function of the time of year, as well as the actual value of the PHDI. For example, despite the fact the correlation between the PHDI and $\hat{P}$ during August in Alabama is only -0.35, much of the important variance of $\hat{P}$ is captured by categorizing the relationships by month. In northern Alabama, over 78% of the variance of $\hat{P}_i$ is explained by PHDI_{i-1} in this regard. When viewed in terms of the annual cycle of $\hat{P}$, the PHDI_{i-1} generally explains most of the variance of $\hat{P}_i$. For the 344 climate divisions tested, one-third had over 90% of the variance of $\hat{P}$ explained by equations such as those in Fig. 1, while only 3 of 344 climate divisions had less than the 50% of the variance of $\hat{P}_i$ explained by the value of PHDI_{i-1}.

Once a relationship has been established between the value of the PDSI (or PHDI) at the end of a month and $\hat{P}$ for the subsequent month for each climate division, then the solution to (12) can proceed. In the calculation of $\hat{P}_i$ from (12) the values of K_i usually range from just over 0.5 in wet climates to nearly 3.5 in dry climates. It is apparent that during severe droughts, the first term of (12), (Z_i/K_i), dominates the magnitude of P_i for short recovery or amelioration times, but as the drought intensity decreases and the recovery or ame-

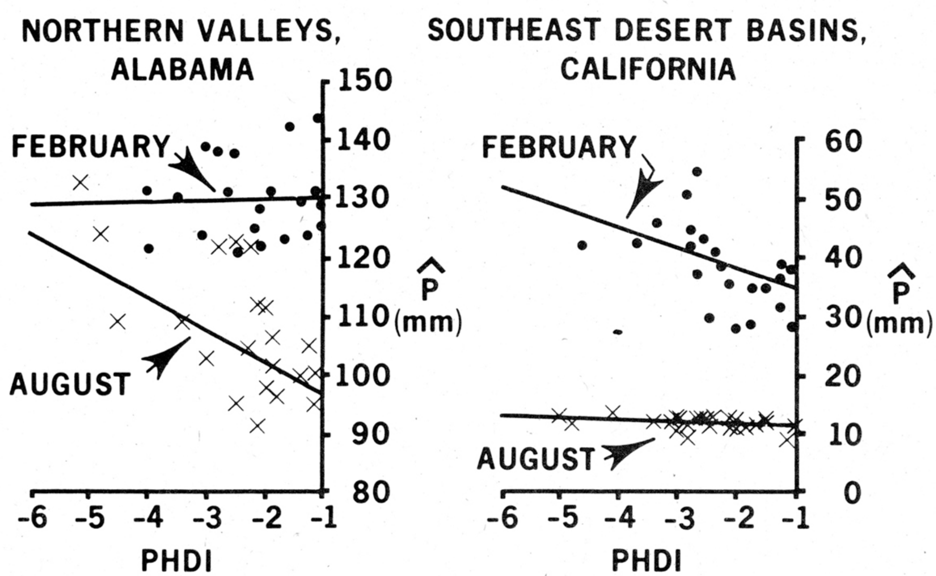

FIG. 1. Least-squares fit of the CAFEC (Climatologically Appropriate for Existing Conditions) precipitation ($\hat{P}$) versus the PHDI.

lioration time increases, $\hat{P}_i$ dominates the magnitude of P_i.

In Table 3, the value of Z_a is negative for a level −3 drought and a 6-month amelioration time period. This is not an error, but rather the result of an intentional philosophy of the PDM; namely, over a sufficiently long period, near-normal precipitation will end a drought and moisture conditions will gradually return to normal. This implies that in order to maintain a drought, the precipitation must regularly fall short of P_i. In regions that have a very pronounced annual cycle of normal soil moisture (such as southern California), it is sometimes possible, although quite infrequent, that the total precipitation required to terminate a drought in 2 months (or 3 months) may be less than that required in 1 month (or 2 months). This can occur when the water storage in the soil decreases rapidly from month to month on a routine basis. Since the concept of the PDM is based on departures from normal [(2) and (12)], Z_e for a 1-month-ending period will always be greater than Z_e for a 2-month-ending period. Whenever K_i is considerably smaller for the nearer more-moist month than the more distant drier months (as occurs during the spring in portions of California), the total precipitation needed to end a drought can be larger for the 1-month period compared to the 2-month period. Simply stated, the precipitation required to end a drought as calculated in the PDM is the precipitation needed to bring moisture conditions back to near normal for specific months. In regions with large annual precipitation soil-moisture cycles, the precipitation needed to bring soil-moisture conditions to normal in two months may be less than the precipitation needed to bring conditions to normal in one month.

3. Data

The data used to calculate the precipitation required to end or ameliorate a drought consisted of the U.S. National Climatic Data Center's climate division temperature and precipitation data (Karl et al., 1983). These data spanned the years 1931–84 for 344 climate divisions in the contiguous United States. Each climate division is constrained to state borders. All National Weather Service first- and second-order stations, as well as cooperative stations which report both temperature and precipitation, are included in the climate division data. Times of observation biases have been removed from the temperature data using the model described by Karl et al. (1986). The PDM was run and calibrated using the full period of record 1931–84.

4. Probability calculations

After calculating the precipitation needed to terminate or ameliorate droughts of various intensities over 1, 2, 3, and 6-month periods, the climatological probability of receiving such an amount was calculated using the gamma distribution following the procedures described by Crutcher et al. (1980). This distribution has long been used in fitting and transforming various meteorological variates, especially precipitation (Panofsky and Brier, 1958; Thom, 1951, 1958; Barger et al., 1959; Thom and Vestal, 1968). Implicit in these calculations is the fact that such probabilities do not consider the time distribution of precipitation within these periods, and that the precipitation anomalies over 1, 2, 3, and 6 months act as white noise or random walk processes. As Karl (1983) points out, there is evidence to indicate that dry spells actually persist longer in the central portion of the United States than along the periphery of the nation. Nonetheless, since the predominant character of the precipitation in all portions of the country at monthly, seasonal, and annual time periods is white noise, these unconditional probabilities should prove useful both in the context of operational applications and climatological studies.

5. Preliminary concepts

Before presenting and discussing the results of the probability calculations for termination and amelioration of drought, it will be beneficial to review the physical and mathematical properties of the PDM which will help speed or delay the rate of drought recovery or amelioration. The times of the year which will be most favorable for ending a drought will first, and most importantly, have the capability of producing values of Z as large as those given in Tables 2 and 3. This will, for most practical purposes, rule out the possibility of recovering from a serious drought when the probability of obtaining enough precipitation to produce high values of Z is low. For example, the climate of the northern plains during winter and the west coast during summer is such that excessively heavy precipitation does not occur. On the other hand, during seasons when the moisture anomaly index, Z, can obtain higher values, it does not necessarily follow that the wettest months will be the times when the probability of terminating or ameliorating a drought will be the greatest, because the PDM is based on departures from normal. During the wetter months, the month more likely to end the drought of serious magnitude would be the month which has a higher probability of obtaining high values of Z. This is not necessarily the wettest month, but rather the month that has a greater probability of substantial excess precipitation compared to normal, i.e., those months with the largest positive skew. Using these concepts, the results of the probability calculations can be more readily understood.

6. Results

Figure 2a depicts the PHDI for Hudson Valley, New York along with the precipitation required to terminate any drought less than −1.5 within two months. The minimum precipitation required to end a drought was estimated using the values of Z_e given in Table 2

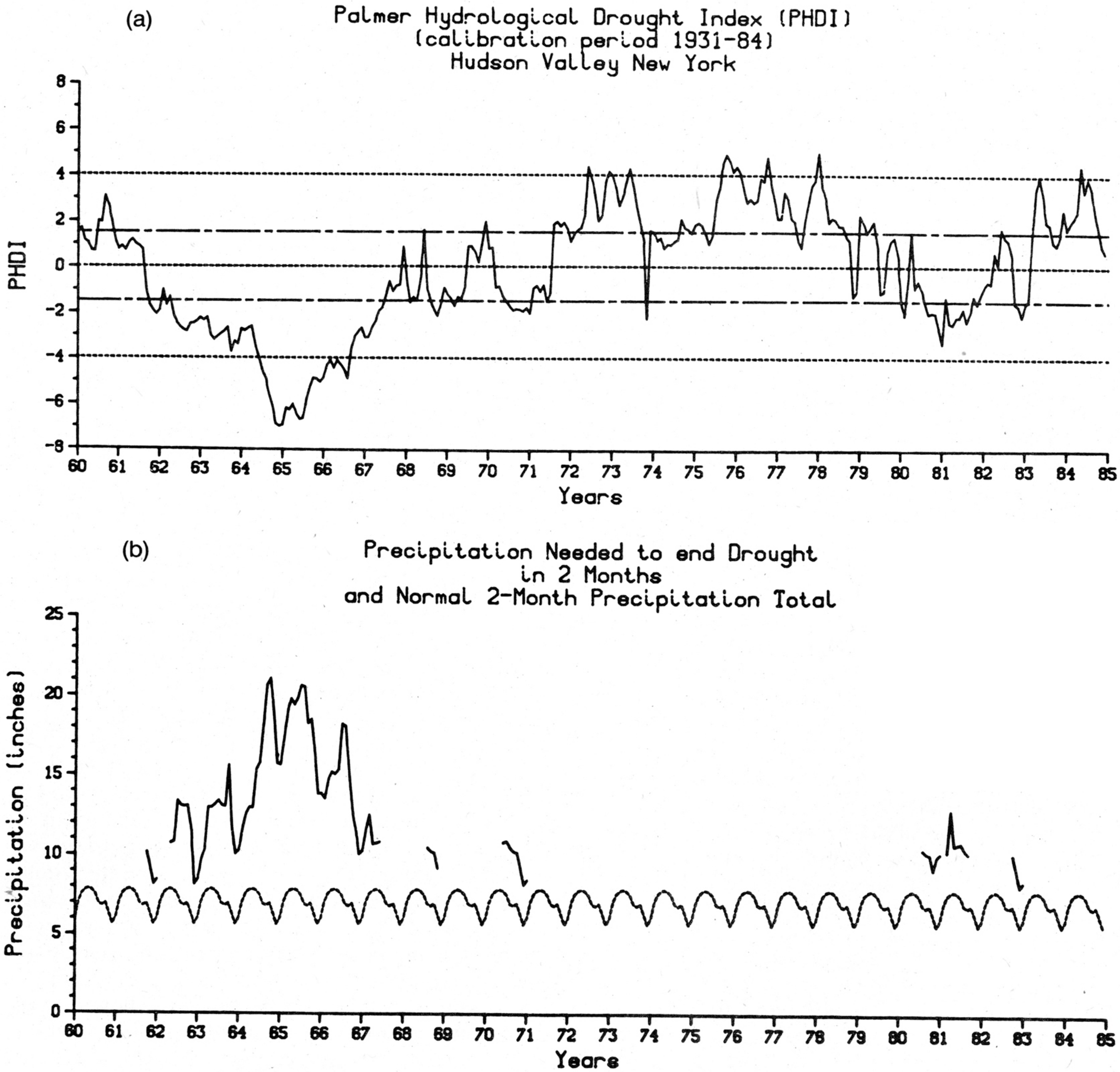

FIG. 2. Simultaneous time series of the PHDI, the normal two-month total precipitation, and the precipitation required to terminate a drought with intensity less than −1.5 for two climate divisions: (a) Hudson Valley and (b) south central Nebraska.

rounded to the nearest integer. For comparison, the normal 2-month total precipitation is also plotted each month. Figure 2a qualitatively illustrates the improbability of ending the extreme drought in the mid-1960s within a short time (two months). During the peak intensity of the drought (PHDI < -4) 200 to 300% of the normal 2-month total precipitation would have been required to terminate the drought in such a rapid time span. Contrarily, the weaker drought of 1980–81, even at its peak intensity, could have ended within two months with less than 200% of its normal 2-month total precipitation.

In Fig. 2b the seasonal standardization concept of the PDM is illustrated for south central Nebraska. The seasonal fluctuations of the precipitation required to end the drought closely follow the pronounced annual cycle of the 2-month total precipitation, characteristic of this portion of the country. In south central Nebraska during the devastating drought of the 1930s and 1950s, nearly seven times the normal 2-month total precipitation was required to end the intense drought during the winter, and at least three times the normal 2-month total precipitation was required during spring and early summer.

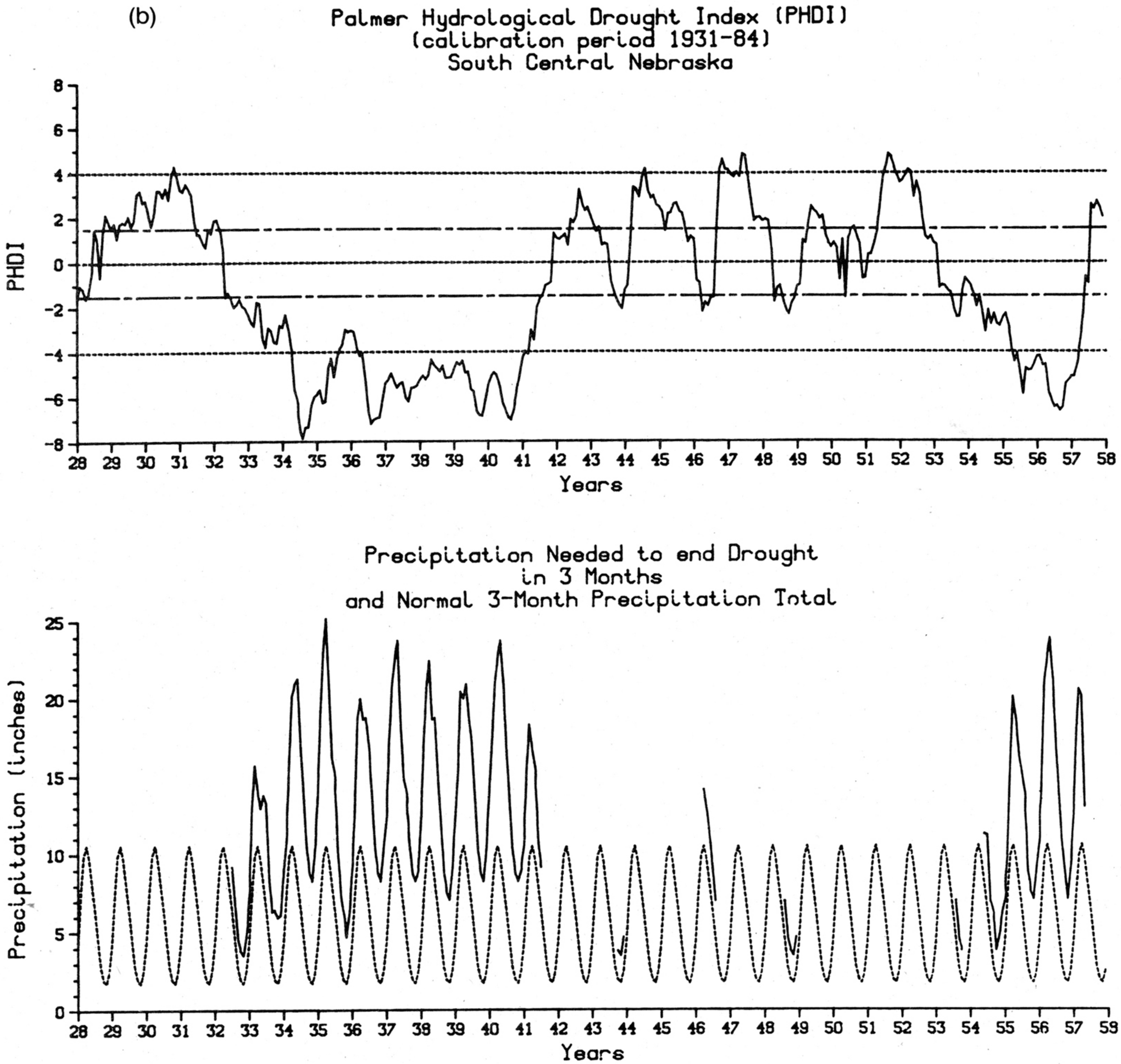

FIG. 2. (*Continued*)

The march of the seasons, as reflected by monthly mean total precipitation for each of nine regions of the country delineated by a rotated principal-component analysis (cf. Karl and Koscielny, 1982), is given in Fig. 3. The precipitation depicted in Fig. 3 is derived from "gridded" statewide average precipitation within each region. These regions were delineated by statewide gridded values of the PDSI over the United States, and will serve as a useful reference in helping to explain the probabiity calculations for drought termination and amelioration.

Over the contiguous United States, the probability of ending a severe drought (PHDI = −3) or ameliorating an extreme drought (PHDI = −4) in 1 month is rather low, even for the month with the highest probability of ending or ameliorating a drought (cf. Fig. 4). Regionally, the highest probability of ending (or ameliorating) a severe (or extreme) drought occurs along the West Coast during the late fall. This is often the onset of the wintertime precipitation regime and the time when evapotranspiration is considerably below its early fall levels. These conditions provide the opportunity for serious droughts to be mitigated and ended. In areas where the distribution of precipitation is relatively constant throughout the year, such as in the East, the probabilities, as depicted in Fig. 4, are substantially lower than areas with a more pronounced annual precipitation cycle. In these areas, the months

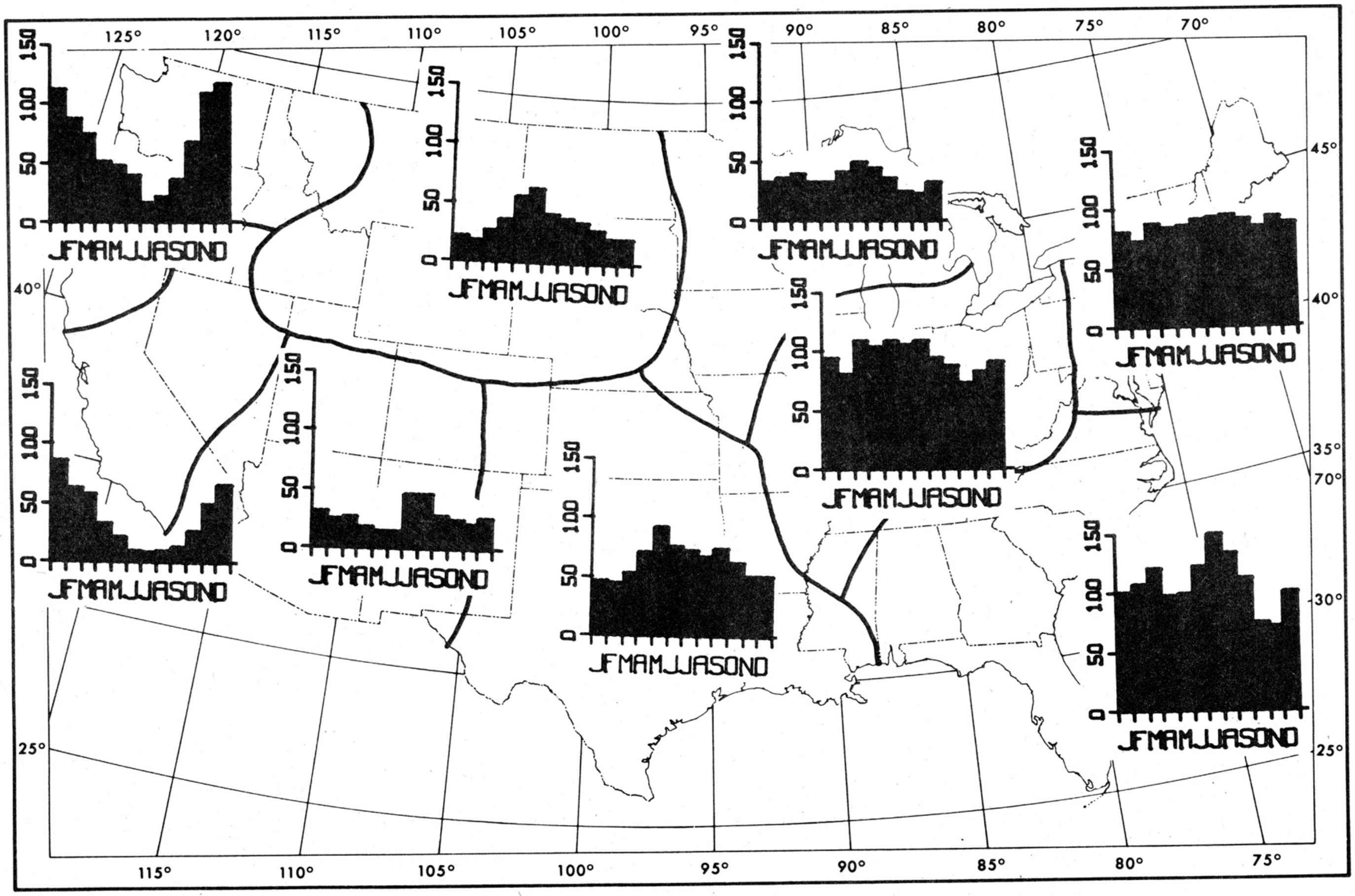

FIG. 3. Mean monthly total precipitation (millimeters) in each of nine regions delineated by a rotated principal component analysis of the PDSI (from Karl and Koscielny, 1982).

more likely to end or ameliorate serious droughts are those months when the probability of receiving relatively heavy precipitation compared to the normal is largest. Examples of such behavior can be documented in Figs. 4 and 5. In Fig. 5, the 90th and 50th percentiles of monthly total precipitation are derived from the gamma distribution (U.S. Department of Commerce, 1985). The period of record from which the percentiles were derived was 1951–80. Figure 4 indicates that the preferred month for ending and ameliorating severe droughts in portions of the South and Southeast is October. For these areas, Fig. 5 reveals a peak in the ratio of the 90th percentile to the 50th percentile total monthly rainfall in October as depicted by the Monroe, Louisiana and Columbia, South Carolina stations. A 1-month earlier, flatter peak in the ratio of the two percentiles at Goldsboro, North Carolina helps change the preferred month of drought mitigation from October in South Carolina, to September in much of North Carolina. The tendency for early fall recovery/amelioration in southern and southeastern portions of the United States is likely to be at least partially associated with the frequency of tropical storms and hurricanes during this period. Farther west, Pocatello, Idaho has a much more pronounced annual precipitation cycle, but the large peak of the ratio of the 90th to the 50th percentile plays an important role at this location. The preferred ending and amelioration time of the serious droughts occur during September when there is a broad but strong peak in the ratio. September is the preferred month for ending and amelioration of droughts for a large area of the upper Mississippi Valley and the lower Great Lakes. For Madison, Wisconsin and Peoria, Illinois this is reflected in the September peak of the ratio of the 90th to the 50th percentile of total monthly precipitation. Farther east in New England the preferred ending and amelioration months are variable; this is reflected by the relatively flat monthly precipitation cycle (cf. Fig. 3), as well as the ratio of the two percentiles plotted in Fig. 5.

Having established some important characteristics influencing drought termination and amelioration in the PDM, the results in Fig. 6 with respect to the magnitude and timing of the highest and lowest probabilities of ameliorating an extreme drought over a 3-month period can be more readily understood. In the dry season in the southwest United States there is virtually no chance of ameliorating an extreme drought, and a similar scenario emerges for the northern plains during the winter season. Contrarily, in the East and

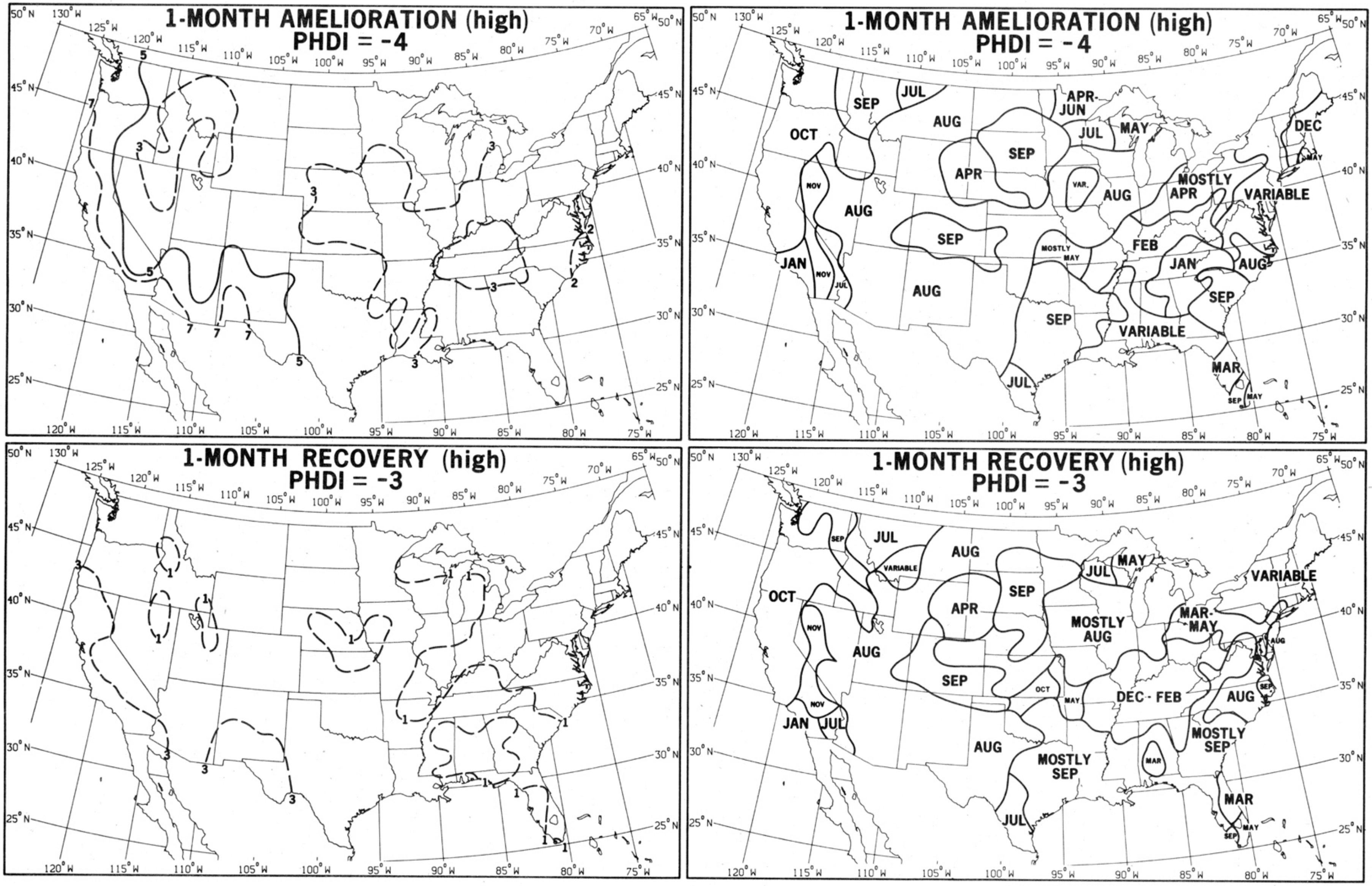

FIG. 4. The months with the highest probability (in percent) of having a severe drought (PHDI = −3) terminated in the next month and the months with the highest probability of having an extreme drought (PHDI = −4) ameliorated in the next month.

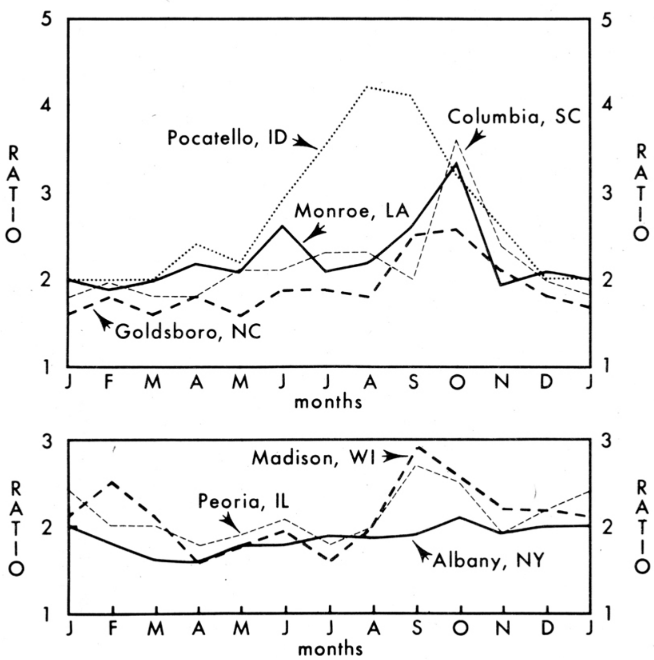

FIG. 5. Ratios of the 90th to the 50th percentile of total monthly precipitation for selected stations.

South the probabilities of ameliorating extreme drought over a 3-month period never reach such low values. Nonetheless, the highest probabilities of ameliorating an extreme drought within 3 months occur during the wet season along the West Coast. In the central Great Plains the probability of ameliorating extreme droughts is relatively low throughout the year. Such a result suggests that droughts in this portion of the country tend to persist longer than in other areas of the country. This has also been shown by Karl (1983) using the PDSI in a sensitivity study.

Figure 7 is presented to depict the relatively long time—at least 6 months—usually required to end a drought of −4 magnitude over the same period. In fact, for portions of the Pacific Northwest it is more likely than not that a drought of this magnitude will ameliorate within 6 months. This may not be too surprising, however, because the Z_a for this category is quite small, 0.05, and the wet season for this part of the country is relatively long (cf. Fig. 3). The highest probabilities of terminating a serious drought are found along the West Coast during the cold seasons (cf. Fig. 4).

The question arises whether the months associated with the highest probability of ending or ameliorating an ongoing drought are the same months with the lowest probability of strengthening an ongoing drought. The months most likely to have the greatest decrease in the PHDI can be found using the technique already described in section 2, by producing tables similar to Table 2 and 3, except for PDSI_i equal to such extreme values such as −6, −5, −4, etc. This has been done. In addition, the maximum precipitation that can occur in order to reach these extreme values over 1-, 2-, 3- and 6-month intervals has been calculated, as well as the probability of having less than or equal to the maximum precipitation allowed. Table 4 summarizes these calculations for 1- and 2-month interval calculations for the climate divisions which contain the stations depicted in Fig. 5. None of the 1- or 2-month intervals with the highest probability of drought intensification match the months depicted in Fig. 4 with respect to being most conducive to drought termination/amelioration. Despite this fact, the months with the lowest probability of drought intensification do not always match those months listed in Fig. 4. For example, in central Illinois it is not possible to intensify a drought from −3 to −4 during the months of October through February, as negative precipitation would be needed (cf. Table 4), yet the month of September is depicted as the month most conducive to drought amelioration or termination (Fig. 4). For central Illinois this is attributed to the fact that evaporation during these cold season months is relatively low and the median or expected precipitation for these months is also relatively low compared to other months. Precipitation deficiencies in any single month during this time of the year are not as important and cannot match those during the warmer months when evaporation is high and the expected amount of rainfall significantly higher. Note that this is not true for 2-month time intervals. Generally, precipitation deficiencies during these warmer months can have a greater impact on the magnitude of the PHDI.

7. Conclusions

The PDM is often used as a tool for monitoring ongoing droughts across the nation. The results presented in this paper will help those users more accurately assess the chances of drought recovery during times of serious drought. This information can be used as an aid in decisions regarding implementation of water conservation or rationing procedures. Karl et al. (1986) have prepared an atlas of probabilities and precipitation needed to end droughts of various magnitudes over 1, 2, 3, and 6 months.

Results from this work have shown that not only does the annual cycle of precipitation affect the time period most likely to end a drought, but in addition, the likelihood of receiving relatively heavy precipitation compared to the normal precipitation should also be considered. Both of these characteristics are important time- and space-varying properties of drought climatology in the United States. The probability of ending droughts in the United States has a pronounced annual cycle in the West, but a much-reduced annual cycle in the East. Once a serious drought is underway, the probability of recovering or ameliorating is usually less for interior portions of the country than the probabilities farther east or west.

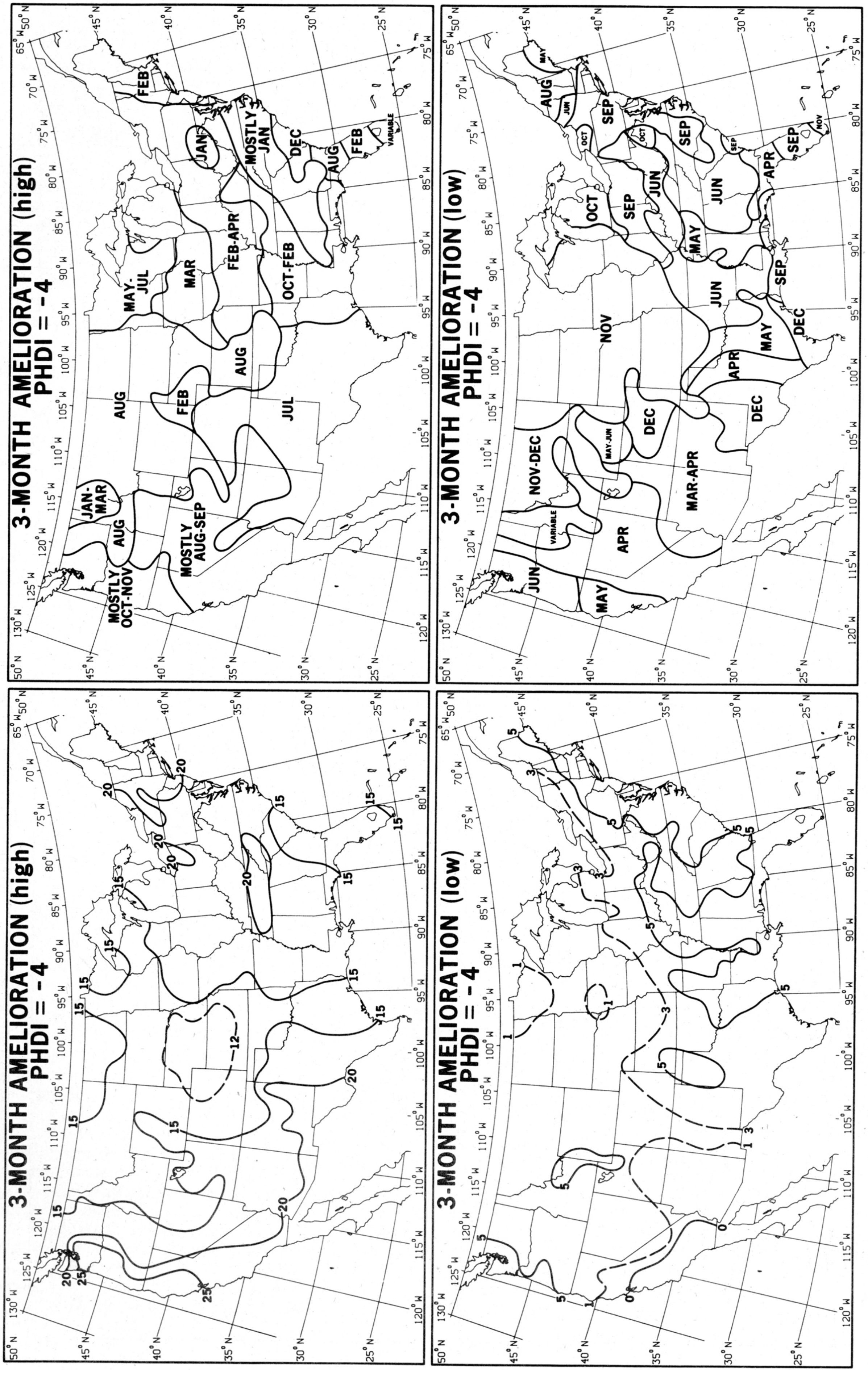

FIG. 6. The months with the highest and lowest probability (in percent) of having an extreme drought (PHDI = −4) ameliorated over the subsequent three-month period.

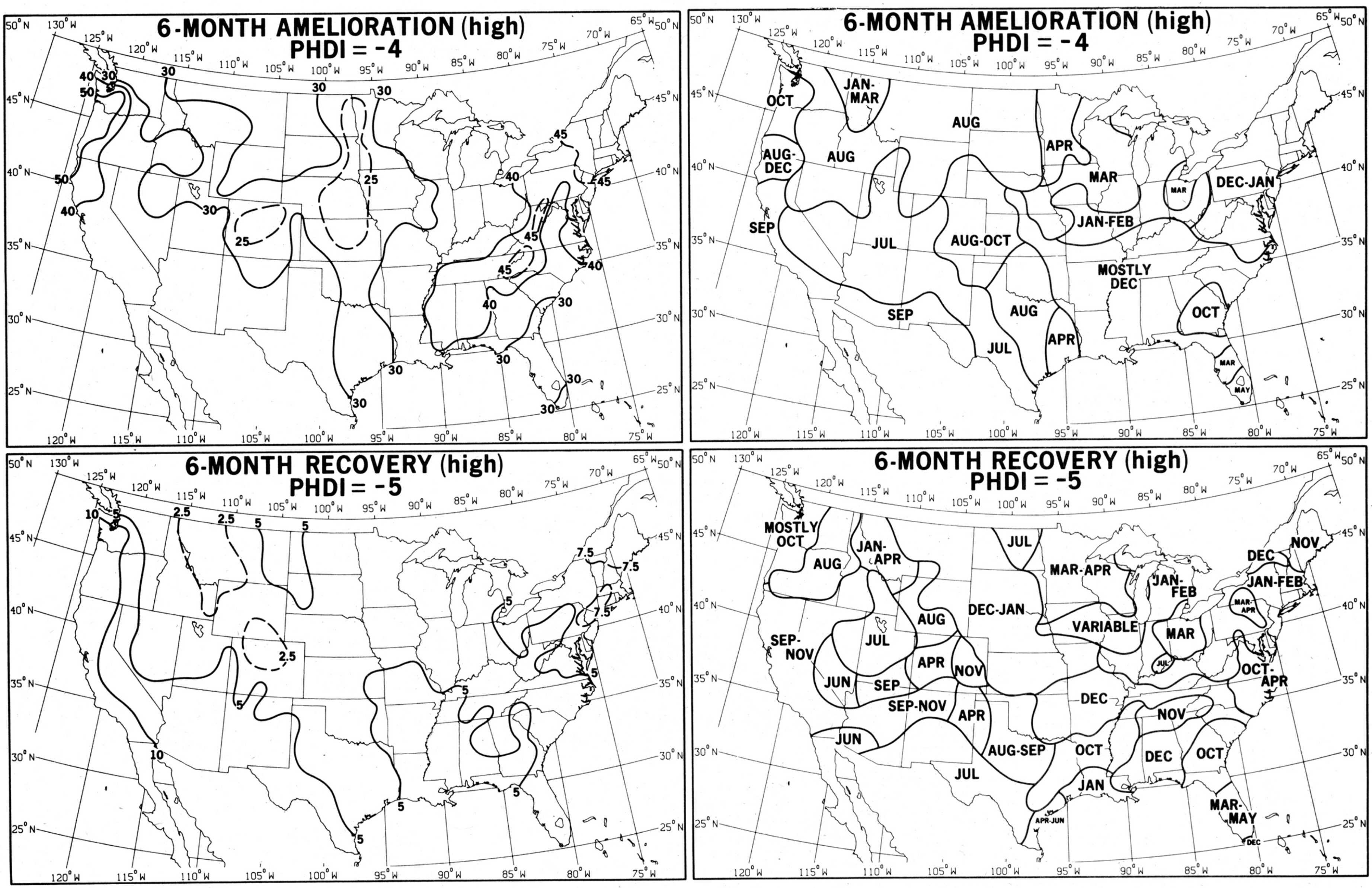

FIG. 7. The months with the highest probability (in percent) of having an extreme drought (PHDI = −4) ameliorated over the subsequent 6 months and an even more extreme drought (PHDI = −5) terminated over a 6-month period.

TABLE 4. The month with the highest or lowest probability of having a severe drought (PHDI = −3) becoming an extreme drought (PHDI = −4) in the next 1 or 2 months and its associated probability (in percent).

Climate division, state	Highest probability		Lowest probability*	
	1 month	2 months	1 month	2 months
Upper Snake River plains, Idaho	May (0.3)	May (27.9)	Jun to Apr NP	Aug NP
Northeast La.	Feb (0.1)	Jun (4.6)	Mar to Jan NP	Aug (<0.1)
Central coastal plain, N.C.	Jun (2.0)	Oct (15.0)	Sep NP	Mar (0.2)
Central S.C.	Aug (0.5)	Jul (7.4)	Sep to Apr NP	Sep (0.3)
Central Ill.	Jun (0.1)	Oct (15.0)	Sep to Jan NP	Dec (2.2)
South central Wis.	Jun (0.4)	Oct (13.2)	Aug to Feb NP	Dec (<0.1)
Hudson Valley, N.Y.	Oct (0.8)	Sep (10.1)	Dec NP	Jan (0.2)

* NP implies it is not possible to achieve a −4 drought intensity in the given time interval.

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